Gendered Differences in Accidental Trauma to Upper and Lower Limb Bones at *Aquincum*, Roman Hungary

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Abstract

It is hypothesized that men and women living in the border provinces of the Roman Empire may have encountered different physical dangers associated with variation in their occupations and activities. Limb bone trauma data were used to assess sex-based differences in physical hazards and evidence for fracture healing and treatment. Two hundred and ten skeletons were examined from a late 1st to early 4th century AD cemetery at *Aquincum* (Budapest, Hungary). Upper and lower limb bone fracture types, frequencies, distributions, and associated complications were recorded, and gendered patterns in injury risks were explored. Of the 23 fractures identified, both sexes had injuries indicative of falls; males exhibited the only injuries suggestive of higher-energy and more direct forces. Most fractures were well-healed with few complications. The extremity trauma at *Aquincum* suggests that people buried here experienced less hazardous physical activities than at other Roman provincial sites. The patterns of trauma indicate that "traditional" gender roles were in place, whereby male civilians participated in more physically dangerous activities than females. Additionally, treatment may have been equally accessible to men and women, but certain fracture types proved more challenging to reduce using the techniques available.

Keywords: *long bone trauma; fracture treatment; underfoot accident; injury risk;* Pannonia

1. Introduction

The border provinces of the northern Roman Empire were diversely populated by indigenous people, soldier's families, veterans, and crafts-people (Allason-Jones 1999; Snape 1989; Whittaker 1994). Civilians living in provincial communities participated in a wide variety of industrial, commercial, and agricultural activities to provide food, goods, and other services essential to support the Roman Empire and its armies (Elton 1996; Hajnalová and Rajtár 2009; Whittaker 1994). Despite their important role in provincial society, the daily experiences of men, and especially women, in the Roman provinces are unclear. In order to better understand how risks and physical hazards differed between the sexes in these regions, this study examines the types and distribution patterns of fractures to the upper and lower limb bones (i.e., clavicle, humerus, radius, ulna, femur, tibia, fibula) in adult skeletons from the civilian town of *Aquincum* (Budapest, Hungary), a capital city in the Roman province of *Pannonia*. By illuminating fracture causes and evidence for poor healing, the upper and lower limb bone trauma at *Aquincum* may provide insight into the existence of gendered activities and differential access to treatment at the margins of the Roman world.

Fractures are partial or complete breaks to bone, caused by an acute traumatic event, repeated stress/strain over time, or are secondary to an underlying pathological or "insufficiency" condition such as osteoporosis (Hamblen et al. 2007; Peris 2003). Bone will break according to recognizable patterns that can be used to interpret the causative mechanism (e.g., direct or indirect trauma, intermittent stress) and forces applied to a bone (e.g., tension, compression, torsion, flexion, shearing) (Alms 1961; Egol et al. 2010; Galloway et al. 2014a; Hamblen et al. 2007). When contextualized with available archaeological and historical information, interpretations of fracture forces and mechanisms can potentially provide insight into the types of hazards that caused fractures in the past.

The degree to which a provincial citizen was at risk for injury varied by their occupation and day to day activities, both of which were influenced by their status, age, and gender (Allison 2007; Redfern and DeWitte 2011b). In this study, the term ‘gender’ refers to an individual’s social identity, while ‘sex’ refers to the sexually dimorphic features in male and female skeletons (Hollimon 2011; Walker and Cook 1998). Palaeopathological analysis may be used to infer gendered activities through the identification of differences in the patterns and prevalence of skeletal lesions between biologically sexed male and female skeletons (Hollimon 2011; Sofaer 2006; Walker and Cook 1998).

Accidents related to mobility and loss of balance, clinically called “underfoot accidents”, can affect both sexes, however women are typically at greater risk for injury than men (Davies et al. 2003; Manning 1983). Underfoot injuries include falls caused by *trips*, which occur when a swinging leg is abruptly interrupted upon impact with an object or body part, and *slips*, which are the loss of heel friction and “skidding” of the supporting leg(s) (Davies et al. 2003; Manning 1983; Redfern et al. 2001; Zecevic et al. 2006). Falls (both slips and trips) commonly cause fractures to bones of the wrist when an individual tries to break their impact with an outstretched hand (Nevitt and Cummings 1993; Verma et al. 2008). Another type of underfoot injury, regularly caused by ankle instability on uneven surfaces, results in oblique or avulsion fractures to the distal part of the tibia or fibula due to abrupt over- pronation or supination of the foot at the ankle joint (Cooper 2000; Court-Brown et al. 1998; Donatto 2001; Manning 1983). These types of fractures have been previously observed in other Roman provincial contexts (e.g., Croatia: Novak and Šlaus 2010; and Britain: Redfern 2003), and are expected to be present at most sites in the Roman world.

Aside from everyday mobility hazards, men in the Roman period may also have been involved in dangerous military, agricultural, animal husbandry, and construction activities (Erdkamp 1999; Giardina 1993b; Redfern and DeWitte 2011b). The documented female occupations were comparably less physically demanding, but women were by no means relegated to private spaces and domestic roles (Allison 2007; Scheidel 1995). In the public sphere, women worked in shops, food establishments, crafts and trades, some of which may have been more physically challenging (e.g., brick makers, olive pickers) than others (e.g., midwives, scribes) (Allison 2007; Flemming 2013; Gardner 1986; Giardina 1993b). Extremity fractures that are indicative of greater forces or higher energy mechanisms include oblique and spiral fractures that are often related to falls or jumps from a height (Johner et al. 2000; Petaros et al. 2013; Smith et al. 2006), as well as transverse fractures, associated with direct blows from other people (interpersonal violence), accidents involving animals, or damage from the use of tools (e.g., mallets, spades, and hoes), equipment (e.g., carts, ploughs), and construction materials (e.g., heavy wooden beams or stones) (Sölveborn 2007).

In addition to injury hazards in antiquity, there were also risks associated with fracture healing. A fracture's healing potential is influenced by the type of bone fractured, the mechanical stabilization applied, if any, as well as an individual's age and general health. Today, effective fracture healing is influenced by a person's diet, medications, activity level, co-morbidities, as well as nutritional and metabolic deficiencies (e.g., vitamin D deficiency) (Gaston and Simpson 2007; Mirhadi et al. 2013). People in antiquity were aware of techniques for non-surgical realignment (reduction) and stabilization of fractured bones using splints and poultices (Brorson

2009; Celsus 1961; Hippocrates 2004; Redfern 2010). However, the application of these treatments may not always have been successful due to treatment incompetence or personal non-compliance (Redfern 2010). Fracture complications, including infection, osteoarthritis, and mal- and non-union, may also provide insight into fracture severity and possible treatment interventions, and yield information about social stability and living conditions in the past (Dellinger et al. 1988; Grauer and Roberts 1996; Karladani et al. 2001). Infection can be a complication of compound fractures, when broken bone ends pierce the skin and enable bacteria to enter the wound (Dellinger et al. 1988); this non-specific infection can cause recognizable bony reactions, including periosteal new bone and osteomyelitic changes (Ortner 2003). Osteoarthritis (OA) may develop following trauma, particularly in the case of poorly aligned fractures and injuries involving joints (Anderson et al. 2011; Rogers and Waldron 1995). Imperfectly aligned, or mal-united, fractured bone segments occur as a result of poorly reduced and stabilized fractures (Hamblen et al. 2007). Fracture fragments can also sometimes fail to join (non-union fractures), resulting in sealed medullary cavities with dense sclerotic bone (McKee 2000). Well-healed fractures, the most frequently recognized injuries in archaeological contexts, would not need stabilization in death. As such, appliances used for treatment, for example splints, are not usually buried with the deceased (Roberts 1988b). If they were, it is unlikely that they would preserve archaeologically due to the biodegradable nature of most Roman medical interventions, including splints, poultices, and bandages made from organic materials such as wood, wool, oil, and fabric (Hippocrates 2004; Redfern 2010; Roberts 1988b).

To evaluate physical risks to Roman civilian health, this study uses data collected from fractured upper and lower limb bones from Graphisoft, the site of a 1st to 4th century cemetery associated with the *Aquincum* civilian settlement. We hypothesize that males in this Roman border community encountered greater hazards in their lives than the females. This outcome would be in agreement with other provincial Roman studies that have found males to be at greater risk for mortality, possibly due to differences in ‘environmental stressors associated with employment’ (Redfern and Dewitte 2011a; Redfern and DeWitte 2011b, p. 203). *Aquincum* males are expected to have a higher overall fracture prevalence and demonstrate injury types that are associated with strenuous activities. While we expect that fractures will mimic a traditional, or “safe” model of gendered activities (i.e., men are soldiers, women are weavers) (terminology after Casella 2006), it is anticipated that both sexes will have fractures suggestive of underfoot accidents, reflective of daily life in a Roman city. Furthermore, observation of mal-united fractures at *Aquincum* will provide evidence for ineffective fracture care, and suggest possible limitations in accessing or adhering to successful injury treatments at this civilian location. This study’s investigation of sex differences in limb bone trauma provides insight into the injury risks encountered by women and contributes to our understanding of gendered roles/activities in border cities of the Roman Empire. The distribution of injury complications between the sexes may also potentially provide information about gendered barriers to healthcare in provincial Roman, urban centers.

2. Material and Methods

Located in the northeastern corner of the Roman province of *Pannonia*, modern Budapest, Hungary (Figure 1), the settlement at *Aquincum* included a legionary fortress with an associated military town (*canabae*), and a second, civilian, town (*municipium*, later *colonia*) two kilometers north of the legionary fort (Hajnóczi et al. 1995; Németh 2003; Zsidi and Furger 1997). In the early 2nd century AD, the “civil town” (*municipium*) was promoted to become the capital of *Pannonia inferior*, and was home to ten to fifteen thousand people at its peak in the 3rd century AD (Hajnóczi et al. 1995; Láng 2013; Németh 2003; Zsidi and Furger 1997). Reportedly, instability caused by border conflicts and raids resulted in the gradual depopulation and the abandonment of both the civil town and *canabae* in the 4th century AD (Christie 1992; Hajnóczi et al. 1995; Láng 2013; Zsidi 2002).

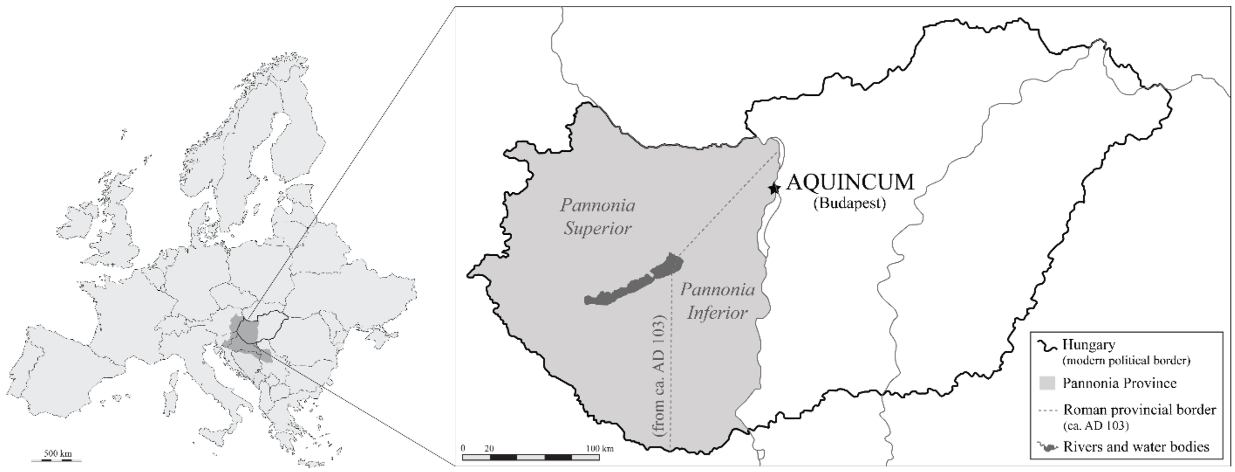

Figure 1 ***Pannonia inferior*** **and** ***superior*** **(grey) superimposed on a modern political map of Hungary.** ***Aquincum*** **is located at modern day Budapest, Hungary, in the northeast corner of** ***Pannonia inferior.*** **The full extent of the Pannonian province is depicted on the larger political map. Roman borders adapted from Visy (2003) and modern political boundaries adapted from Google Maps (Google 2014).**

Part of a cemetery associated with the civil town at *Aquincum* was excavated between 2005 and 2010 by Aquincum Museum archaeologists prior to construction work at Graphisoft Park (an area known in some earlier publications as the Óbuda Gas Factory), Budapest, Hungary (Lassányi 2007; Lassányi 2008; Lassányi 2010; Lassányi 2011). The "Graphisoft" cemetery contained inhumation and cremation burials both dated to between the late 1st and early 4th centuries AD. The majority of burials were interred during the height of *Aquincum's* Roman occupation between the 2nd and 3rd centuries AD (Lassányi 2007). The cemetery is thought to have served middle class residents of the town, and while some cremations had richer inclusions, most inhumations were simple earth-cut graves with few to no grave goods (Lassányi 2007). At the time of analysis (2009), the curated Graphisoft skeletal assemblage included 605 inhumation burials; excavations were ongoing, and the skeletal collection has since grown.

For inclusion in this study, skeletons had to be aged at a minimum of 20 years old at death, with confident sex-estimations, and relatively well-preserved long bones (i.e., clavicle, humerus, radius, ulna, femur, tibia, and fibula). Long bone fractures were analyzed because they can be good indicators of the environment in which people lived, and are also reflective of the activities and even occupations they undertook (Judd 2002b). Additionally, fractures to long bones would have been sufficiently debilitating for medical intervention to have been sought (Grauer and Roberts 1996).

Skeletal age and sex were estimated by Zsolt Bernert at the Hungarian Natural History Museum, Budapest (Bernert 2009). Sex was estimated by scoring 23 characteristics outlined in Éry (1992) and Éry et al. (1963). Adult age was estimated using degeneration of the pubic symphyseal face (Brooks and Suchey 1990), the sternal ends of ribs (Íșcan et al. 1985; Íșcan et al. 1984), and cranial suture closure (Meindl and Lovejoy 1985; Nemeskéri et al. 1960). In instances of poor preservation, dental attrition scores were used to place individuals within a broad age group (Éry 1992; Huszár and Schranz 1952). At the time of analysis 605 inhumations from Graphisoft had been excavated and curated, 444 were adults; 210 of these adults (95 females [45.2%] and 115 males [54.8%]), met the study inclusion criteria (Table 1). Each individual was classified into an age category as outlined by Martin and Saller (1957): *adultus* (18/20-35/40 years old), *maturus* (35/40-50/60 years old), *senilis* (60+ years old). Individuals estimated as between 35 and 40 years were categorized as *adultus*. Individuals with age estimates too broad for a single category were classified as “adult”. Long bones were partitioned into five segments, three diaphyseal and two epiphyseal (after Judd (2002b)); the preservation of each segment was estimated to the nearest quarter percentile (i.e., 0%, 25%, 50%, 75%, 100%). All segments greater than 75% preserved were classified as "complete" and were included in the analyses.

Age Category	Male	Female	?	Total
Adultus	56 / 108 (51.9%)	72 / 162 (44.4%)	0 / 12	128 / 282 (45.4%)
Maturus	51 / 72 (70.8%)	16 / 32 (50.0%)	0 / 1	67 / 105 (63.8%)
Senilis	2 / 5 (40.0%)	2 / 2 (100%)	0 / 0	4 / 7 (57.1%)
Adult	6 / 29 (20.7%)	5 / 18 (27.8%)	0 / 3	11 / 50 (22.0%)
Total	115 / 214 (53.7%)	95 / 214 (44.4%)	0 / 16	210 / 444 (47.3%)

Table 1 The number of Graphisoft individuals included in this study sample, relative to the total number of individuals in the Graphisoft skeletal assemblage (available at the time of analysis). The percentage of the total group included in this study is also provided.

Cremations were not available for study, but were deemed unsuitable for inclusion due to fragmentation. Omission of cremated individuals and inclusion of only 210 of the available 444 adult inhumations means that some individuals with fractured bones may have been overlooked. However, approximately half of the individuals in each sex and age category are included and the sample was considered to be representative of the cemetery population.

2.1 Fracture Recording and Radiography

Healed long bone fractures were identified based on the abnormal contour of bone in comparison with the unaffected, contralateral side, or a representative "normal" bone. All the broken ends of bones were examined for evidence of perimortem trauma. Perimortem trauma can be mistaken for post-mortem breaks, however living bone has plasticity and elasticity that is absent in dry bone, resulting in distinctive smooth-edged breaks, typically not at right angles to the bone contour, and of a color similar to the rest of the bone (Galloway et al. 2014b; Ubelaker and Adams 1995; Wheatley 2008). Individuals who survived for a short time after injury may exhibit woven bone formation at the fracture site, indicative of early callus formation (Hamblen et al. 2007; Lovell 2008; McKinley 2003). As time progresses, more bone is deposited, and eventually consolidates into organized, dense, lamellar bone (Hamblen et al. 2007; Lovell 2008). Fractures with evidence of new bone formation, and therefore healing, were classified as antemortem.

A combination of macroscopic and radiographic methods were used to record the bone element, side, and segment in which the fracture was present and the type of fracture that had resulted. All healed fractures were radiographed alongside their contralateral side using a GE Legend 210 X-ray machine at the Department of Diagnostic Radiology and Oncotherapy, Semmelweis University Medical School (Budapest, Hungary); x-ray intensities and exposure times averaged 46 kV, 3.8 mAs, and 0.02 s. As per clinical standards, at least two perpendicular views (i.e., antero-posterior [AP] and medio-lateral [ML]) were obtained for each fracture; multiple views assist in characterizing fracture lines, displacement, and deformity as they occur in different planes (American College of Radiography 2013; Roberts 2000; Roberts 1988b). Radiographs were used to identify the type of fracture as transverse, oblique, spiral, crush, impaction, avulsion, or incomplete. Transverse fractures, caused by tensile stresses, have fracture lines angled less than 45 degrees from the bone contour, whereas oblique fractures are caused by compressive and shearing stresses and have fracture lines greater than 45 degrees (Galloway et al. 2014a; Rogers 1992). Spiral fractures, caused by torsion forces, result in “twisted” fracture lines; avulsion fractures are produced when a tendon or ligament under stress pulls off (avulses) a piece of bone (Alms 1961; Egol et al. 2010; Galloway et al. 2014a).

Factors limiting the observation and interpretation of archaeological trauma have been reviewed in detail by Roberts (2000). These include difficulties in recognizing and interpreting some fractures and fracture types such as perimortem fractures, as well as thoroughly-healed, incomplete, and stress fractures, which may have few macroscopically or radiographically observable features. Furthermore, fracture type only permits discussion of the mechanism behind the injury, and does not allow identification of the precise fracture cause. This impedes differentiation between some accidental and intentional traumas as they may both result in similar fracture types; for example, ulnar diaphyseal fractures may be produced during an accidental fall, or by a blow (i.e., parry fracture) (Judd 2008; Judd and Redfern 2012). Finally, barring the application of destructive analyses (e.g., Boer et al. 2012) or indirect inference of age from fractures sustained at particular developmental stages (Duchesneau and Fallat 1996; Lovejoy and Heiple 1981; Verlinden and Lewis 2015), it is typically not possible to determine the age at which many healed fractures were sustained, or in the case of multiple fractures, if the injuries occurred simultaneously or resulted from multiple events.

Fractures that have not been properly reduced or stabilized may heal with mal-union in the form of displacement (i.e., angulation and/or rotation), poor apposition, overlap of fracture segments, as well as overall shortening of the bone itself (Frost 1989; Lifeso and Younge 1990). Mal-union is typically indicative of failed or lack of treatment and can result in a variety of consequences, including the development of secondary osteoarthritis, dysfunction, and pain (Karnezis et al. 2005; Van Der Schoot et al. 1996). To assess unsuccessful fracture healing in the past, a model suggested by Roberts (1988a) used radiographs and patient records of living British people with conservatively treated (i.e. reduced and traditionally splinted with an external cast), simple fractures. Through comparisons with “modern” British patient records, Roberts’ (1988a) study suggested displacement, apposition, overlap, and shortening values were indicative of fractures that were untreated or where treatment failed (Table 2). However, it should be noted that untreated fractures in nonhuman primates have been shown to heal with minimal deformity (e.g., see Lovell 1990), just as conservatively treated fractures in humans today can still heal with some deformity (Milner et al. 2002). Although the direct application of modern clinical data to people who lived in the past may be problematic (i.e., modern groups experience different diets and co-morbidities that can affect the effectiveness and rate of fracture healing), Roberts' (1998a) study is the only one to synthesize and quantify aspects of fracture mal-union as it relates to conservative treatment (analogous to the past), and is justified in helping to evaluate failed treatment or determining if a fracture may have been treated.

Element Type	Degree of deformity constituting unsuccessful healing
Femur	>30 mm shortening >35° linear deformity >50 mm overlap
Tibia	>15° linear deformity >10mm overlap
Tibia and fibula	>15° linear deformity >35mm overlap
Humerus	>20° linear deformity >15mm overlap
Radius	> 25° linear deformity >15mm overlap
Radius and ulna	>25° linear deformity

Table 2 Degrees of deformity constituting unsuccessful fracture healing (reproduced from Grauer and Roberts (1996); after Roberts (1988a)).

The current study assessed mal-union (displacement, apposition, and overlap of the two fracture fragments) based on the position of the distal segment relative to the proximal (Roberts 1988b). Angulation was measured radiographically using a goniometer aligned to the medullary mid-line of each fracture fragment (Grauer and Roberts 1996; Roberts 1988b) (Figure 2). Apposition represents the proportion of two fracture segment ends that are in contact with each other (Figure 3). The diameters of the fractured bone ends, measured to the outer cortical surfaces, were used to evaluate the percent apposition at a fracture site; when two bone fragment ends were in correct anatomical alignment they were in 100 percent apposition (Equation 1) (Grauer and Roberts 1996; Roberts 1988b). The approximate degree and direction of rotation estimated with a protractor described via visual comparison with the non-fractured contralateral bone (Figure 4). Fracture displacement and overlap were measured to the nearest millimeter with a standard ruler placed directly on the radiograph (Figure 3). Overlap of fracture fragments, as well as angulation of the bones at a fracture site, can change the length of a fractured bone, which in turn has the potential to negatively influence functional outcome (Batra and Gupta 2002). When possible, the length of the fractured element was measured and compared to its non-fractured opposite.

Figure 2 Healed fracture angulation, measured using a goniometer (i.e., a ruler and a protractor), representing the degree the distal segment is angled away from an anatomically positioned proximal fragment. Image depicts a spiral fracture to the right radius of 2008.14.045, a *maturus* male.

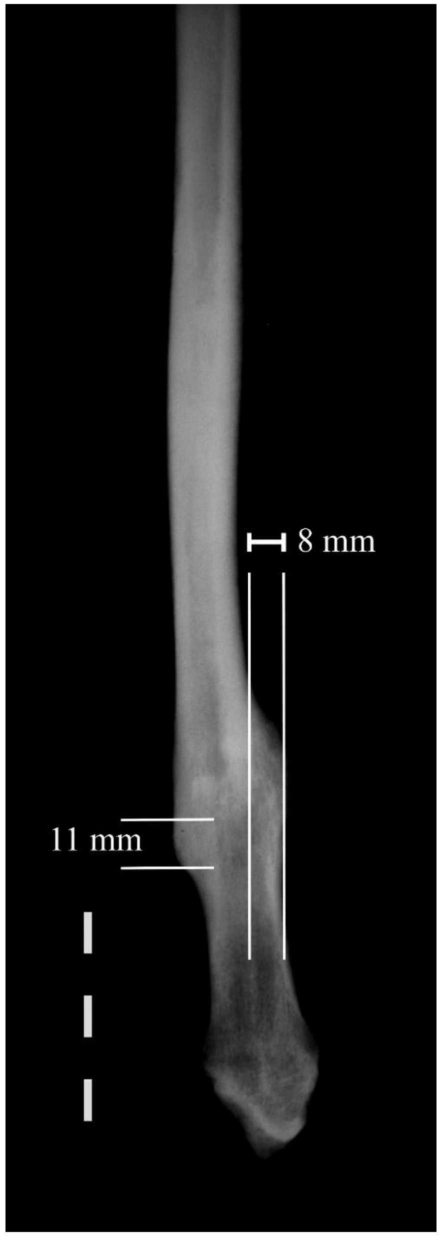

Figure 3 Healed fracture with displacement and overlap is measured using a ruler placed on the radiograph. This image represents an oblique fracture to the left fibula of individual 2008.14.434. The distal segment is displaced by 8mm towards the anterior, resulting in a calculated apposition of 56%. The fracture segments have an overlap of 11mm.

$$\%\,Apposition = 100\% - \left(100\ \times \left[\frac{displacement\ (mm)}{normal\ cortical\ diameter\ (mm)}\right]\right)$$

Equation 1 The measured amount of displacement is divided by the normal cortical bone diameter to estimate the percent displacement. The difference between this value and 100% represents the percentage of the distal fracture fragment that is in line (apposed) with the proximal fragment.

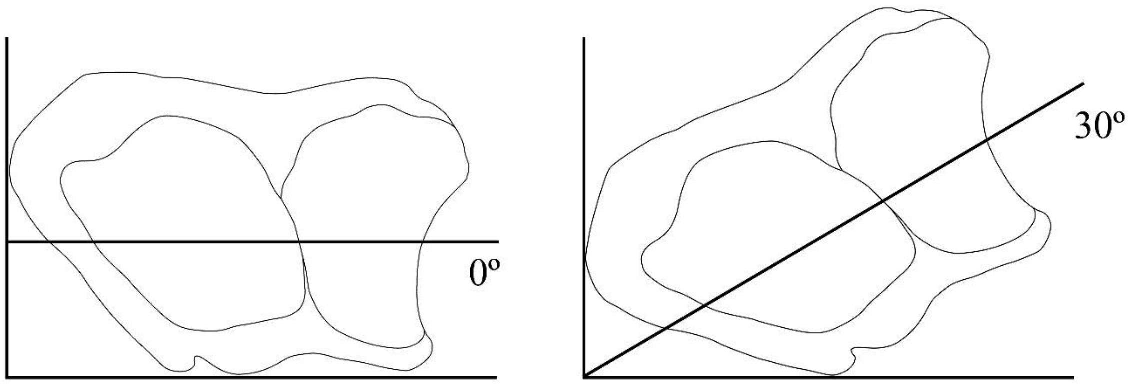

Figure 4 The approximate amount and direction that the distal segment is rotated, estimated by comparing the fractured with the non-fractured contralateral bone. The distal radius depicted represents "normal" (left) and approximately 30º anterior rotation (right) of the medial aspect of the bone.

In addition to mal-union, other potential complications of the fracture, including inflammation (a response to possible infection), blood vessel and nerve damage, and osteoarthritis (OA), were recorded. Inflammation was identified based on the presence of periosteal new bone formation and/or osteomyelitic changes at or adjacent to the fracture site (Boutin et al. 1998; Lovell 2008; Ortner 2003). Nerves and blood vessels can be damaged during a traumatic event, or due to movement of sharp fractured bone ends (Hamblen et al. 2007; Wraighte and Scammell 2006). If a nerve is severed, function may be lost in the elements distal to the injury location, resulting in visible muscle and later bone atrophy (DeFranco and Lawton 2006); the presence of skeletal asymmetry was thus recorded when present. Vascular injuries, especially those affecting arteries, can cause rapid and life threatening blood loss (Hamblen et al. 2007). If an individual dies from blood loss, it is unlikely that the associated fractures will have had sufficient time to heal and produce new bone. OA was identified when eburnation was observed, or when at least two of the following characteristics were present: osteophyte formation, porosity, joint contour shape change, or new bone formation on the subchondral surface (Rogers and Waldron 1995). It is important to note that it was not possible to be certain that these degenerative changes developed as a result of the fracture; this is especially the case for OA where older people may naturally develop this condition (Loeser 2009).

Fracture prevalence was calculated in two ways to improve accuracy when using poorly preserved and fragmentary skeletal material (Judd 2002b; Lovell 2008). Crude prevalence rates (CPR) compared the total number of fractures (n_f) to the total number of individuals (N_i) (Equation 2). True prevalence rates (TPR) calculated fracture frequencies by comparing the total number of fractured elements with the number of bones observed that had at least one segment greater than or equal to 75% complete (N_e) (Equation 3). TPR calculated in this manner accounts for the fragmentary nature of archaeological skeletons and calculates a more realistic fracture frequency based on the bones that are actually available for observation. CPR calculations counted individuals with multiple trauma only once, while TPR included all fractured elements regardless of the number of individuals involved. To compensate for the fragmentary nature of the skeletal collection, every observed fracture was included in all calculations, regardless of preservation.

$$CPR = 100\ (n_f /\ N_i)$$

Equation 2 Crude prevalence rate of fractures at the individual level (CPR) is calculated by dividing the total number of fractures observed (n_f) by the number of individuals analyzed (N_i) (after Lovell 2008).

$$TPR = 100\ (n_f /\ N_e)$$

Equation 3 Fracture prevalence in complete bones (true prevalence rate, TPR) is calculated by dividing the total number of fractures observed (n_f) by the number of complete elements observed (N_e) (after Judd 2002b, p. 1258).

Differences among bone elements, segment locations, fracture types, and healing complications (e.g., OA, angulation) were compared using descriptive statistics. Two by two contingency tables (one degree of freedom) were constructed for all statistical tests. Odds ratios (OR) with 95% confidence intervals (CI) were used to evaluate the strength of relationships between two groups of binary variables; values greater or less than 1.0 indicated differences in fracture probability and 1.0 meant there was no difference between groups (Bland and Altman 2000). Fracture counts were evaluated for statistical significance using Chi Square tests with Yates' corrections to account for small fracture sample sizes (x^2_{Yates}) (fracture counts presented in Results section). Fisher exact tests (P_{FET}) were used to assess statistically significant differences between variables that did not meet the sample size requirements of the Chi Square test (i.e., expected frequencies of five and above). Results were considered significant at $p \leq 0.05$.

2.2 Comparative Populations

Despite a long tradition of archaeological and historical research on the Roman world and border provinces, there are limited bioarchaeological reports that include detailed trauma data. Archaeological projects continue to identify Roman funerary contexts, but many identified cemetery sites have low numbers of individuals and the oft-unpublished commercial archaeological reports can be difficult to access. Furthermore, although standardized trauma reporting is encouraged (e.g., Roberts 2000), many studies still do not present true prevalence rate data.

Three urban, late Imperial (3rd to 4th centuries AD) provincial cemeteries and one composite collection of four rural cemetery sites were selected for comparison based on the skeletal sample size, documentation of fractures by sex and TPR, and location in an outer Roman province (Table 3). These included: 191 adult skeletons from *Colonia Iulia Iader*, a large urban harbor city in modern Zadar, Croatia (Novak and Šlaus 2010); 300 adults from Cirencester, UK, one of the larger urban centers in Romano-Britain (McWhirr et al. 1982; Wells 1982); 188 adults from Lankhills, Winchester, UK, a smaller urban, *civitas* capital (Booth et al. 2010); and 245 adults from 'Continental Croatia', a composite site of skeletal remains from four rural sites at

Viknovici, Osijek, Ŝtrbinci, and Zmajevac, Croatia (Novak and Šlaus 2010). Lankhills and Cirencester are included as urban comparators in a distant Roman peripheral province (i.e., *Britannia*), Zadar was included as an urban center that is geographically close to *Aquincum*. The Continental Croatian sites, albeit rural, were the only suitable sites identified that represented fractures in *Pannonian* border communities. Fracture frequency data, odds ratios, and Fisher exact tests were used to compare Graphisoft with other Roman sites.

Site	Roman Province	Site Type (urban/rural)	Date Range	N_i Males	N_i Females	N_i Adults Total	Reference
Aquincum, Graphisoft, Budapest Hungary	*Pannonia*	Urban	1st - 4th centuries AD	115	95	210	Bernert (2009)
Continental Croatia	*Pannonia*	Rural	4th – 5th centuries AD	127	118	245	Novak and Šlaus (2010)
Colonia Iulia Iader, Zadar, Croatia	*Dalmatia*	Urban	3rd - 4th centuries AD	111	80	191	Novak and Šlaus (2010)
Venta Belgarum, Lankhills School, Winchester, UK	*Britannia*	Urban	4th century AD	94	94	188	Booth et al. (2010)
Corinium Dobunnorum, Fosse Way South, Cirencester, UK	*Britannia*	Urban	4th century AD	207	93	300	Wells (1982)

Table 3 Skeletal data used for comparison with Graphisoft.

3. Results

Twenty-three fractures were present in 20 of the 210 Graphisoft skeletons (N_i=20/210, CPR=9.5%) (Table 4), and affected 1.0% of all observed long bones (N_e=23/2308) (Table 5). A total of 10.4% of males and 8.4% of females exhibited trauma; twelve males had 14 fractures (N_e=14/1284, TPR=1.1%) and eight females had nine fractures (N_e=9/1024, TPR=0.9%) (Table

5). The odds that males had more fractures than females were low (OR=1.2, CI 0.5-2.9) and not statistically significant (x^2_{Yates}=0.09; df=1; p=0.77). One perimortem fracture was identified in the right femur of an *adultus* male (2008.14.472) (see Discussion, Figure 10). No non-union fractures were observed. The age of one male (2008.14.041) could not be confidently determined, and this fractured right radius was excluded from age-based analyses.

Skeleton Number	Sex	Age Category*	Element	Side	Fracture Type	Fracture Timing	Segment**	OA	Angulation (º)	Apposition (%)	Approx Rotation (º)	Overlap (mm)
2008.14.020	M	*Adultus*	Humerus	Left	Transverse	Antemortem	MD	/	16	100	25	0
2008.14.028	F	*Adultus*	Ulna	Left	?	Antemortem	DD	/	/	/	/	/
2008.14.041	M	Adult	Radius	Right	?	Antemortem	MD	/	2	70	5	/
2008.14.044	M	*Maturus*	Ulna	Left	?	Antemortem	DD	Elbow	8	100	/	0
2008.14.045	M	*Maturus*	Radius	Right	Spiral	Antemortem	MD	Elbow, Wrist	19	65	100	10
2008.14.062	F	*Adultus*	Ulna	Left	?	Antemortem	DD	/	/	/	/	/
2008.14.069	F	*Adultus*	Radius	Right	Impaction	Antemortem	DE	Wrist	0	/	0	/
2008.14.090	M	*Maturus*	Radius	Left	Oblique	Antemortem	DE	Wrist	19	85	10	12
2008.14.132	M	*Maturus*	Tibia	Right	Avulsion	Antemortem	DE	Ankle	/	90	25	/
2008.14.132	M	*Maturus*	Ulna	Right	Avulsion	Antemortem	PE	Elbow	n/a	n/a	n/a	n/a
2008.14.153	M	*Maturus*	Tibia	Left	Oblique	Antemortem	MD	/	5	80	0	15
2008.14.184	F	*Maturus*	Radius	Right	Oblique	Antemortem	DE	None	15	95	5	6
2008.14.184	F	*Maturus*	Ulna	Left	Crush	Antemortem	DE	Wrist	/	/	0	/
2008.14.215	M	*Maturus*	Radius	Right	Transverse	Antemortem	DD	/	21	50	80	4
2008.14.228	F	*Adultus*	Radius	Left	Oblique	Antemortem	DE	None	14	/	15	/
2008.14.233	F	*Maturus*	Humerus	Right	Oblique	Antemortem	DD	Elbow	18	75	0	11
2008.14.280	M	*Maturus*	Radius	Right	Oblique	Antemortem	DE	None	10	80	0	4
2008.14.323	F	*Adultus*	Ulna	Left	Avulsion	Antemortem	PE	Elbow	/	/	/	/
2008.14.427	F	*Adultus*	Fibula	Right	Oblique	Antemortem	DD	None	5	75	0	0
2008.14.434	M	*Adultus*	Fibula	Left	Oblique	Antemortem	DD	Ankle	4	56	0	11
2008.14.434	M	*Adultus*	Tibia	Left	Avulsion	Antemortem	DE	Ankle	/	/	5	0
2008.14.459	M	*Maturus*	Ulna	Right	Avulsion	Antemortem	PE	Elbow	/	/	0	/
2008.14.472	M	*Adultus*	Femur	Right	Spiral	Perimortem	MD	None	perimortem	n/a	0	n/a

Table 4 Fractures observed in the Graphisoft cemetery assemblage.
/ = not observable due to postmortem damage, soil intrusion, and/or thorough healing. *after Martin & Saller (1957). **Proximal epiphysis (PE), proximal diaphysis (PD), middle diaphysis (MD), distal diaphysis (DD), distal epiphysis (DE).

Elements	Age	Male			Female			Total		
		n_f	N_e	TPR	n_f	N_e	TPR	n_f	N_e	TPR
Clavicle	*Adultus*	0	80	0.0	0	102	0.0	0	182	0.0
	Maturus	0	89	0.0	0	22	0.0	0	111	0.0
	Senilis	0	0	0.0	0	3	0.0	0	3	0.0
	Adult	0	4	0.0	0	0	0.0	0	4	0.0
	Sub-Total	0	173	**0.0**	0	127	**0.0**	0	300	**0.0**
Humerus	*Adultus*	1	98	1.0	0	131	0.0	1	229	0.4
	Maturus	0	100	0.0	1	31	3.2	1	131	0.8
	Senilis	0	3	0.0	0	4	0.0	0	7	0.0
	Adult	0	5	0.0	0	2	0.0	0	7	0.0
	Sub-Total	1	206	**0.5**	1	168	**0.6**	2	374	**0.5**
Radius	*Adultus*	0	94	0.0	2	119	1.7	2	213	0.9
	Maturus	4	97	4.1	1	26	3.8	5	123	4.1
	Senilis	0	3	0.0	0	4	0.0	0	7	0.0
	Adult	1	7	14.3	0	5	0.0	1	12	8.3
	Sub-Total	5	201	**2.5**	3	154	**1.9**	8	355	**2.3**
Ulna	*Adultus*	0	88	0.0	3	116	2.6	3	204	1.5
	Maturus	3	94	3.2	1	26	3.8	4	120	3.3
	Senilis	0	2	0.0	0	4	0.0	0	6	0.0
	Adult	0	7	0.0	0	5	0.0	0	12	0.0
	Sub-Total	3	191	**1.6**	4	151	**2.6**	7	342	**2.0**
Upper Limb Subtotal	*Adultus*	*1*	*360*	0.3	*5*	*468*	1.1	*6*	*828*	0.7
	Maturus	*7*	*380*	1.8	*3*	*105*	2.9	*10*	*485*	2.1
	Senilis	*0*	*8*	0.0	*0*	*15*	0.0	*0*	*23*	0.0
	Adult	*1*	*23*	4.3	*0*	*12*	0.0	*1*	*35*	2.9
	Sub-Total	***9***	***771***	***1.2***	***8***	***600***	***1.3***	***17***	***1371***	***1.2***
Femur	*Adultus*	1	102	1.0	0	133	0.0	1	235	0.4
	Maturus	0	95	0.0	0	28	0.0	0	123	0.0
	Senilis	0	4	0.0	0	2	0.0	0	6	0.0
	Adult	0	8	0.0	0	9	0.0	0	17	0.0
	Sub-Total	1	209	**0.5**	0	172	**0.0**	1	381	**0.3**
Tibia	*Adultus*	1	82	1.2	0	115	0.0	1	197	0.5
	Maturus	2	84	2.4	0	24	0.0	2	108	1.9
	Senilis	0	2	0.0	0	2	0.0	0	4	0.0
	Adult	0	4	0.0	0	8	0.0	0	12	0.0
	Sub-Total	3	172	**1.7**	0	149	**0.0**	3	321	**0.9**
Fibula	*Adultus*	1	65	1.5	1	80	1.3	2	145	1.4
	Maturus	0	64	0.0	0	16	0.0	0	80	0.0
	Senilis	0	0	0.0	0	2	0.0	0	2	0.0
	Adult	0	3	0.0	0	5	0.0	0	8	0.0
	Sub-Total	1	132	**0.8**	1	103	**1.0**	2	235	**0.9**
Lower Limb Subtotal	*Adultus*	3	249	1.2	1	328	0.3	4	577	0.7
	Maturus	2	243	0.8	0	68	0.0	2	311	0.6
	Senilis	0	6	0.0	0	6	0.0	0	12	0.0
	Adult	0	15	0.0	0	22	0.0	0	37	0.0
	Sub-Total	***5***	***513***	***1.0***	***1***	***424***	***0.2***	***6***	***937***	***0.6***
Total	*Adultus*	*4*	*609*	*1.5*	*6*	*796*	*1.4*	*10*	*1405*	*1.4*
	Maturus	*9*	*623*	*2.6*	*3*	*173*	*2.9*	*12*	*796*	*2.7*
	Senilis	*0*	*14*	*0*	*0*	*21*	*0*	*0*	*35*	*0*
	Adult	*1*	*38*	*4.3*	*0*	*34*	*0*	*1*	*72*	*2.9*
	Total	***14***	***1284***	***1.1***	***9***	***1024***	***0.9***	***23***	***2308***	***1.0***

Table 5 Distribution and true prevalence rates (TPR) of Graphisoft fractured bones (n_f) relative to the number of bone types with complete segments (N_e), divided by sex and age categories. Subtotals for upper and lower extremities also provided.

Fractures were twice as frequent among *maturus* as *adultus* aged individuals (OR=2.1, CI 0.9-5.0; *adultus*: N_e=10/1405, TPR=0.7%; *maturus* N_e=12/796, TPR=1.5%) (Table 5). This difference was not significant when sexes were considered together (x^2_{Yates}=2.50; df=1; p=0.11) or separately (males: P_{FET}=0.26; females: P_{FET}=0.21). No fractures were identified in *senilis* individuals, probably due to the small sample numbers in this age cohort.

Upper limb bones were fractured twice as often as lower limb bones (OR=1.9, CI 0.8-5.0; upper limb N_e=17/1371, TPR=1.2%; lower limb N_e=6/937, TPR=0.6%), but the difference was not significant (x^2_{Yates}=0.68; df=1; p=0.409). Radii and ulnae were fractured the most (female radii/ulnae N_e=7/308, male radii/ulnae N_e=8/392). Males were 2.5 times as likely to fracture their radii/ulnae as any other element (OR=2.5, CI 0.9-7.2; radii/ulnae N_e=8/392, other fractures N_e=6/719), and females fractured radii/ulnae significantly more than other elements (i.e., 6.9 times as often) (P_{FET}=0.009; OR=6.9, CI 1.4-33.2; radii/ulnae N_e=7/308, other fractures N_e=2/592). Most lower extremity fractures were found in males, who were 4.2 times as likely as females to fracture a lower limb bone (CI=0.5, 35.8; male lower limb N_e=5/513, female lower limb N_e=1/424), although this finding is not significant (P_{FET}=0.23).

Fractures were distributed evenly by side (OR=1.1, CI 0.5-2.5; x^2_{Yates}=0.00; df=1; p=0.997; right: N_e=12/1153, TPR=1.0%; left: N_e=11/1155, TPR=1.0%) (Tables 6 and 7). At Graphisoft, epiphyseal segments are preserved less often than diaphyseal segments (see segment counts in Tables 6 and 7), but distal epiphysis (DE) and distal diaphyseal (DD) segments were the most frequently fractured (DE: n_f=8/23, N_e=8/584, TPR=1.4%; DD: n_f=7/23, N_e=7/1807, TPR=0.4%) (Figure 5).

Female														
			Right Segment N_s							Left Segment N_s				
Element	Total n_f	Total N_e	Proximal Epiphysis	Diaphysis Location Proximal	Diaphysis Location Middle	Diaphysis Location Distal	Distal Epiphysis	Total n_f	Total N_e	Proximal Epiphysis	Diaphysis Location Proximal	Diaphysis Location Middle	Diaphysis Location Distal	Distal Epiphysis
Clavicle	0	65	0 / 27	0 / 50	0 / 61	0 / 54	0 / 18	0	62	0 / 24	0 / 47	0 / 53	0 / 52	0 / 18
Humerus	1	83	0 / 8	0 / 70	0 / 78	1 / 79	0 / 16	0	85	0 / 9	0 / 71	0 / 81	0 / 85	0 / 16
Radius	2	76	0 / 13	0 / 58	0 / 68	0 / 60	2 / 14	1	78	0 / 17	0 / 61	0 / 75	0 / 61	1 / 17
Ulna	0	71	0 / 20	0 / 69	0 / 65	0 / 53	0 / 9	4	80	1 / 22	0 / 77	0 / 71	2 / 57	1 / 15
Femur	0	86	0 / 29	0 / 83	0 / 86	0 / 76	0 / 21	0	86	0 / 27	0 / 82	0 / 84	0 / 73	0 / 17
Tibia	0	74	0 / 14	0 / 58	0 / 70	0 / 64	0 / 14	0	75	0 / 14	0 / 64	0 / 73	0 / 64	0 / 17
Fibula	1	53	0 / 2	0 / 42	0 / 48	1 / 46	0 / 7	0	50	0 / 1	0 / 38	0 / 43	0 / 42	0 / 9
Total	4	508	0 / 113	0 / 430	0 / 476	2 / 307	2 / 85	5	516	0 / 92	0 / 440	0 / 480	2 / 377	2 / 77

Table 6 Distribution of fractured bones (n_f) in female individuals from Graphisoft according to segment (n_f / N_s).

Male														
			Right Segment N_s							Left Segment N_s				
Element	Total n_f	Total N_e	Proximal Epiphysis	Diaphysis Location Proximal	Diaphysis Location Middle	Diaphysis Location Distal	Distal Epiphysis	Total n_f	Total N_e	Proximal Epiphysis	Diaphysis Location Proximal	Diaphysis Location Middle	Diaphysis Location Distal	Distal Epiphysis
Clavicle	0	88	0 / 43	0 / 66	0 / 76	0 / 74	0 / 42	0	85	0 / 43	0 / 68	0 / 80	0 / 77	0 / 44
Humerus	0	103	0 / 19	0 / 94	0 / 99	0 / 100	0 / 38	1	103	0 / 17	0 / 87	1 / 97	0 / 101	0 / 36
Radius	4	101	0 / 38	0 / 89	2 / 92	1 / 86	1 / 36	1	100	0 / 29	0 / 88	0 / 90	0 / 85	1 / 37
Ulna	2	94	2 / 43	0 / 90	0 / 87	0 / 73	0 / 23	1	97	0 / 42	0 / 93	0 / 86	1 / 74	0 / 25
Femur	1	104	0 / 46	0 / 101	1 / 100	0 / 89	0 / 29	0	105	0 / 45	0 / 99	0 / 98	0 / 88	0 / 30
Tibia	1	86	0 / 24	0 / 73	0 / 84	0 / 79	1 / 25	2	86	0 / 21	0 / 71	1 / 82	0 / 75	1 / 26
Fibula	0	69	0 / 3	0 / 44	0 / 54	0 / 61	0 / 14	1	63	0 / 4	0 / 46	0 / 53	1 / 61	0 / 17
Total	8	645	2 / 216	0 / 557	3 / 592	1 / 562	2 / 207	6	639	0 / 201	0 / 552	2 / 586	2 / 561	2 / 215

Table 7 Distribution of fractured bones (n_f) in male individuals from Graphisoft according to segment (n_f / N_s).

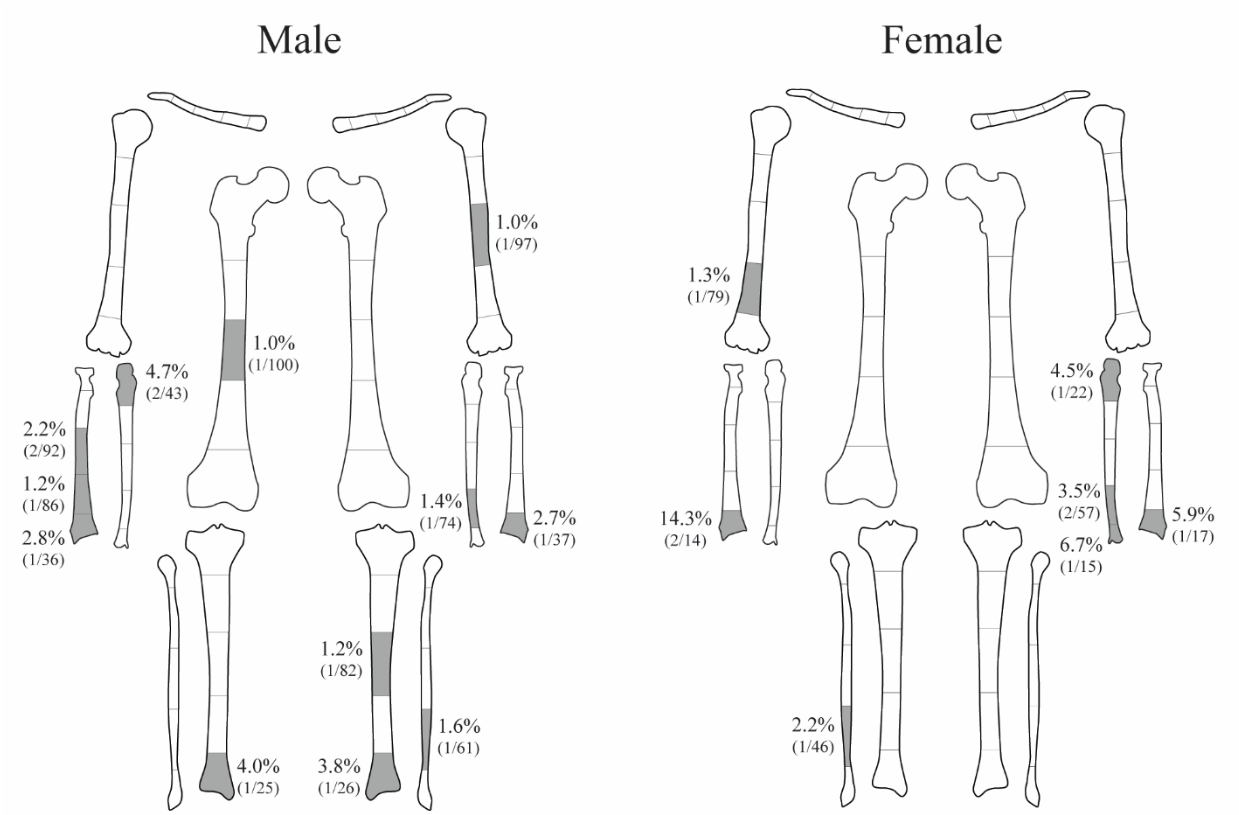

Figure 5 Visual representation of the distribution and prevalence (TPR) of fractures by sex, element, and segment.

Indirect forces explain all the female and half of the male fractures. Oblique fractures were the most common (n_f=8/23), followed by avulsion (n_f=5/23), spiral (n_f=2/23), impaction (n_f=1/23), and crush (n_f=1/23). Only males exhibited direct-force, transverse fractures, including a right radius (2008.14.215, *maturus* male) (Figure 6) as well as a thoroughly healed, possible transverse fracture to a humeral mid-diaphysis (2008.14.020, *adultus* male) (Figure 7). Transverse fractures, together with spiral fractures, represent higher-energy injuries and account for 33% of the male fractures. Males were 4.0 times as likely to exhibit higher energy injuries as females (CI 0.5-34.3), but no significant difference was identified between high and low energy fractures for males and females (P_{FET}=0.25). Multiple trauma were present in three skeletons:

one *maturus* male exhibited a tibial medial malleolus fracture and a proximal ulna avulsion fracture (2008.14.132) (Figure 8), one *maturus* female (2008.14.184) had a Colles fracture to the right wrist and an ulna styloid process crush fracture to the left (Figure 9), and one *adultus* male (2008.14.434) presented with an oblique distal fibula shaft fracture (see Figure 3) and an avulsed tibial medial malleolus. Four fractures could not be identified by type (2008.14.028, 2008.14.041, 2008.14.044, 2008.14.062).

Figure 6 Transverse fracture to the right radius of a *maturus* male (2008.14.215). From left to right, the image depicts the posterior of the actual bone, the AP radiographic view, the lateral bone, and the ML radiographic view.

Figure 7 Right mid-shaft humerus fracture of individual 2008.14.020. Possible transverse fracture. From left to right, the image depicts the anterior of the actual bone, the AP radiographic view, the medial bone, and the ML radiographic view.

Figure 8 Avulsion of supero-medial olecranon process of the right ulna (contralateral olecranon depicted to scale on the left of the image). Paired humerus shown with possible retention of the avulsed fragment or ossified soft tissues.

Figure 9 Colles fracture to the distal end of the right radius in a *maturus* female. Depicted from left to right are the anterior view of the actual bone, the AP radiographic view, the lateral bone, and the ML radiographic view.

The majority of long bone fractures healed with minimal apparent complications. No evidence of periosteal new bone formation or osteomyelitic changes (e.g., cloacae) suggestive of inflammation were associated with any of the fractured elements. However, it is possible for periosteal reactions to have been obscured or lost by postmortem erosion and root etching on the bone surfaces.

None of the Graphisoft fractures exhibited healed deformities that met or exceeded the parameters suggested by Roberts (1988a) for unsuccessful alignment. However, seven of the Graphisoft fractures exhibited linear and/or rotational deformities greater than or equal to 15 degrees. Two *maturus* males (2008.14.045, 2008.14.215) and one *adultus* male (2008.14.020) had deformities ≥15 degrees in both the linear and rotational planes (see Figures 2, 6, and 7). Poor epiphyseal preservation inhibited the calculation of accurate OA prevalence rates, and only 29.4% of joints were present and recordable (N_e=741/2520) (Table 8). Of all the observable long bone joints, 5.1% (N_e=38/741) had OA, and 34.2% of these were associated with fractured bones (N_e=13/38). Osteoarthritis was present in all of the observable adjacent joints with greater than 15 degrees of either rotational or linear deformity.

OA	Right						Left						
	Shoulder	**Elbow**	**Wrist**	**Hip**	**Knee**	**Ankle**	**Shoulder**	**Elbow**	**Wrist**	**Hip**	**Knee**	**Ankle**	**Total**
n OA / n_j	2/29	9/72	4/53	1/89	0/63	1/44	2/30	6/67	9/54	1/96	0/62	3/44	38/703
% OA in preserved joints	6.9	12.5	7.5	1.1	0.0	2.3	6.7	9.0	16.7	1.0	0.0	6.8	5.4
n_f with OA / n_j	0/29	4/72	4/53	0/89	0/63	1/44	0/30	2/67	2/54	0/96	0/62	2/44	13/703
% joints with fractures and OA	0	5.6	7.5	0	0	2.3	0	3.0	3.7	0	0	4.5	1.8
n_f with OA / n_j with OA	0/2	4/9	2/4	0/1	0/0	1/1	0/2	2/6	2/9	0/1	0/0	2/3	13/38
% joints with OA that are also fractured	0	44.4	50.0	0	0	100	0	33.3	22.2	0	0	66.7	34.2

Table 8 Rates of osteoarthritis (OA) present in the preserved joints (n_j) compared to the rates of OA in the adjacent joints of fractured bones. The number of bones with OA that were fractured are also presented.

Graphisoft male fracture frequencies were most similar to Continental Croatia, where the radii/ulnae were fractured at nearly equal frequencies, and the humerus and tibia/fibula had only slightly greater odds of fracture (counts, odds, and significance reported in Table 9). The odds of fracture were greatest among Romano-British males: Cirencester had significantly higher tibial/fibular fracture frequencies (P_{FET}=0.028); Lankhills humerii were 4.1 times as likely to be fractured (CI 0.4-39.8). Zadar also had greater odds of humeral fracture, but relatively equal odds of radial/ulnar and tibial/fibular fracture. Graphisoft female fracture frequencies were likewise most similar to Continental Croatia, but also Lankhills (counts, odds, and significance reported in Table 10), however the odds that a female would have a tibial/fibular fracture were higher at Continental Croatia, and radial/ulnar fracture odds were lower at Lankhills. Female fracture counts were significantly different from Zadar, which had markedly higher odds of humeral, radial/ulnar, and tibial/fibular fractures. It should also be noted that although demographic proportions of a sample may influence fracture prevalence rates (i.e., greater numbers of older people may have accumulated greater numbers of fractures) (see, for example, Glencross and Sawchuk 2003; Lovejoy and Heiple 1981), it was not possible to control for this effect among the comparative sites due to insufficient or incompatible demographic information.

Site	Roman Province	MALE									
			Element (N_e)							TPR Total	Reference
		CPR Total	Clavicle	Humerus	Radius	Ulna	Femur	Tibia	Fibula		
Graphisoft	*Pannonia*	14/115	0/173	1/206	5/201	3/191	1/209	3/172	1/132	14/1284	
		12.2	0	0.5	2.5	1.6	0.5	1.7	0.8	**1.1**	
Continental Croatia	*Pannonia*	12/127	1/161	1/140	3/140	2/135	0/165	4/153	2/143	12/1037	Novak and Šlaus (2010)
		9.4	0.6	0.7	2.1	1.5	0	2.6	1.4	**1.3**	
			-	OR=1.5, CI 0.9, 23.8 P_{FET}=1.0	OR=0.9, CI 0.3, 2.7 P_{FET} =1.0		-	OR=1.5, CI 0.4, 5.6 P_{FET} =0.540		OR=1.1, CI 0.5, 2.3 P_{FET} =1.0	
Zadar, Croatia	*Dalmatia*	12/111	2/126	3/114	1/93	2/100	1/139	3/114	1/120	13/806	Novak and Šlaus (2010)
		10.8	1.6	2.6	1.1	2	0.7	2.6	0.8	**1.6**	
			-	OR=5.5, CI 0.6, 53.9 P_{FET} =0.131	OR=0.8, CI 0.2, 2.9 P_{FET} =1.0		OR=1.5 CI 0.9, 24.3 P_{FET} =1.0	OR=1.3, CI 0.3, 5.3 P_{FET} =0.733		OR=1.5, CI 0.7, 3.2 P_{FET} =0.324	
Lankhills School, Winchester	*Britannia*	16/94	1/53	3/153	2/147	2/147	0/175	4/168	4/131	16/974	Booth et al. (2010)
		17	1.8	1.9	1.4	1.4	0	2.4	3.1	**1.6**	
			-	OR=4.1, CI 0.4, 39.8 P_{FET} =0.316	OR=0.7, CI 0.2, 2.2 P_{FET} =0.569		-	OR=2.1, CI 0.6, 6.9 P_{FET} =0.259		OR=1.5, CI 0.7, 3.1 P_{FET} =0.270	
Cirencester, Fosse Way South, UK	*Britannia*	33/207	3/201	1/205	7/201	4/213	0/242	7/239	11/195	33/1496	Wells (1982)
		15.9	1.5	0.5	3.5	1.9	0	2.9	5.6	**2.2**	
			-	OR=1.0, CI 0.6, 16.2 P_{FET} =1.0	OR=1.3, CI 0.5, 3.3 P_{FET} =0.646		-	OR=3.2, CI 1.1, 9.7 P_{FET} =0.028 *****		OR=2.0, CI 1.1, 3.8 P_{FET} =0.026 *****	

Table 9 Number and prevalence rates (CPR and TPR) of male fractures (n_f) and elements (N_e) in Roman border provinces. Statistical comparisons between Graphisoft and each respective site are indicated by odds ratios (OR) and Fisher exact tests (P_{FET}); radii and ulnae, and tibiae and fibulae were grouped for statistical comparisons. OR values greater than 1.0 indicate that the comparative site had higher odds of fracture than Graphisoft, values less than one mean Graphisoft had higher odds of fracture than the comparative site.

*** statistically significant difference between Graphisoft and the compared site.**
- indicates one or more sites had zero fractures, and could not be reliably compared.

Site	Roman Province	CPR Total	FEMALE Element (N_e) Clavicle	Humerus	Radius	Ulna	Femur	Tibia	Fibula	TPR Total	Reference
Graphisoft	*Pannonia*	9/95	0/127	1/168	3/154	4/151	0/172	0/149	1/103	9/1024	
		9.5	0	0.6	1.9	2.6	0	0	1	**0.9**	
Continental Croatia	*Pannonia*	8/118	2/142	0/97	2/84	2/88	0/140	2/133	0/105	8/789	Novak and Šlaus (2010)
		6.8	1.4	0	2.4	2.3	0	1.5	0	**1**	
			-	-	OR=1.0, CI 0.3, 3.5 P_{FET} =1.0		-	OR=2.1, CI 0.2, 23.6 P_{FET} =0.614		OR=1.2, CI 0.4, 3.0 P_{FET} =0.809	
Zadar, Croatia	*Dalmatia*	13.8	3/94	2/77	2/66	0/54	1/93	0/78	1/77	13/539	Novak and Šlaus (2010)
		16.3	3.2	2.6	9.1	0	1.1	0	1.3	**2.4**	
			-	OR=4.5, CI 0.4, 49.9 P_{FET} =0.233	OR=2.2, CI 0.7, 6.8 P_{FET} =0.206		-	OR=1.6, CI 0.1, 26.2 P_{FET} =1.0		OR=2.7, CI 1.2, 6.6 P_{FET} =0.022 *	
Lankhills School, Winchester	*Britannia*	5/94	0/59	1/155	1/124	1/124	1/161	1/155	0/132	5/910	Booth et al. (2010)
		5.3	0	0.6	0.8	0.8	0.6	0.6	0	**0.5**	
			-	OR=1.1, CI 0.7, 17.5 P_{FET} =1.0	OR=0.3, CI 0.1, 1.7 P_{FET} =0.197		-	OR=0.9, CI 0.1, 14.1 P_{FET} =1.0		OR=0.6, CI 0.2, 1.9 P_{FET} =0.434	
Cirencester, Fosse Way South, UK	*Britannia*	5/93	0/90	0/89	1/71	1/87	0/93	1/95	2/79	5/604	Wells (1982)
		5.4	0	0	1.4	1.1	0	1.1	2.5	**0.8**	
			-	-	OR=0.5, CI 0.1, 2.7 P_{FET} =0.725		-	OR=4.4, CI 0.5, 42.7 P_{FET} =0.309		OR=0.9, CI 0.3, 2.8 P_{FET} =1.0	

Table 10 Number and prevalence rates (CPR and TPR) of female fractures (n_f) and elements (N_e) in Roman border provinces. Statistical comparisons between Graphisoft and each respective site are indicated by odds ratios (OR) and Fisher exact tests (P_{FET}); radii and ulnae, and tibiae and fibulae were grouped for statistical comparisons. OR values greater than 1.0 indicate that the comparative site had higher odds of fracture than Graphisoft, values less than one mean Graphisoft had higher odds of fracture than the comparative site.

*** statistically significant difference between Graphisoft and the compared site.**
- indicates one or more sites had zero fractures, and could not be reliably compared.

4. Discussion

The etiology of all the female (n_f=9), and seven of the male, fractures at Graphisoft are attributable to low-energy, indirect, underfoot accidents, and are likely to reflect normal hazards associated with mobility in the individual's environment. These include three females (two *adultus* and one *maturus*) and two *maturus* males with distal radial (Colles) fractures, one *maturus* female with a distal ulnar crush fracture, and one *maturus* female with a supracondylar humeral fracture, all of which frequently result from a fall on an outstretched hand from a standing height (Egol et al. 2010; Ekholm et al. 2006). One *adultus* female and two *maturus* males have proximal ulna fractures, which can result from landing on, or overextending, the elbow during a fall (Hamblen et al. 2007; Veillette and Steinmann 2008). Three Graphisoft skeletons, one *adultus* female and two males (one *adultus*, one *maturus*), had oblique or avulsion fractures to the medial malleoli and/or distal fibulae, typically caused by over- pronation or supination of the foot (Cooper 2000; Hamblen et al. 2007).

Males have many indirect and direct fractures that are suggestive of riskier activities. Two *adultus* males have one perimortem femur (spiral) fracture (discussed below, see Figure 10) and one probable transverse fracture to a humerus mid-diaphysis (Figure 7). Three *maturus* males exhibit fractures to: one tibia mid-shaft (oblique), one mid-shaft radius (spiral) (Figure 2), and a distal radius diaphysis (transverse) (Figure 6). Clinical data suggest that these types of indirect fractures are often produced by impacts resulting from falls or jumps from a height (Court-Brown and McBirnie 1995; Sims 2002). Transverse fractures are typically produced when a bone directly intercepts a blow, sometimes caused by interpersonal violence, but also often the result of accidental impacts (Alms 1961; Egol et al. 2010).

Four individuals had fractures that were not identifiable by type due to thorough healing or postmortem damage. These include one adult male fracture to a right, mid-shaft radius, and two *adultus* females and one *maturus* male fractures to distal ulnar diaphyses. Minimally displaced, distal ulnar fractures have been used as indicators of interpersonal violence (i.e., parry fractures), however isolated fractures of the distal ulnar diaphysis can also occur by accidental means (Judd 2008). As the type of these ulnar fractures could not be identified, it is not possible to say if these injuries were accidental or the result of interpersonal violence.

During the Roman occupation, the civil town at *Aquincum* was a typical urban setting with archaeological, historical, and epigraphic evidence for crafts, trades, and businesses, including meat and fish markets, lamp, pottery and glassblowing shops, bakeries, fullers, laundries, cobblers, and money changers (Choyke 2003; Láng 2013; Láng 2003; Póczy and Zsidi 2003; Wilkes 2010). The job of an urban merchant was not considered physically laborious in antiquity, and few unique physical hazards are linked with this type of commercial endeavor (Giardina 1993a). In contrast, the people responsible for supplying the merchants with goods, the industries required to produce the raw materials, and the crafts-people who made products, most certainly faced risks associated with tool use, heavier equipment, and animals required for their job (McCarthy 2013; Morel 1993). Industry was likely important at *Aquincum*, as evidenced by a centrally oriented manufacturing district dedicated to bronze-smithing, glue manufacturing, and possible tanning activities (Láng 2013). Heavier trades related to construction, agriculture, and animal husbandry also existed to build and repair the city, as well as contribute to the urban markets (Choyke 2003; Morel 1993; Póczy and Zsidi 2003). Farms, orchards, and vineyards typically surrounded most Roman settlements (Morely 2002), and while some farmers owned and worked their own land, others probably lived in the city and supplied seasonal labor (Engels 1990; Garnsey 2004; Giardina 1993b; White 1970). Finally, traders and importers who moved goods through the Roman world, likely encountered risks related to mobility on foot, with animals and carts, and on ships (Giardina 1993a). However, some evidence suggests that bandits patrolled the countryside between urban centers, adding the risk of interpersonal violence to its inhabitants (Shaw 1993).

Farming and various Roman trades necessitated the use of hand tools (e.g., large ploughs, pick axes, hammers, spades), animals to drive heavier equipment, and jobs that required workers to climb to various heights (e.g., building construction, harvesting fruit) (McCarthy 2013). The use of animals was particularly important in life and work in Roman cities. Large quadrupeds such as oxen, mules, donkeys, and horses were used to plough fields, pack goods, and pull small carts or wagons (Bökönyi 1971; Martin 1990; Toynbee 1973). Animals were used in the city to turn grain mills, operate simple brick making machines, and were also used for ritual sacrifice (Giardina 1993b; Wilson and Schörle 2011). Fractures associated with agriculture and animal handling are documented in clinical and archaeological contexts and can include both direct and indirect fractures (e.g., Judd and Roberts 1999). Clinical studies have found that approximately 40% of modern agricultural injuries are associated with non-mechanical causes related to animals, falls, and hand tool use (Das 2014; Kumar et al. 2008; Pratt et al. 1992). Among modern, non-mechanized agricultural injuries, lower limb bones have the highest incidence of extremity trauma (Criddle 2001; Pratt et al. 1992); the upper extremity is more likely to be fractured in instances when falls are involved (Barber 1973; O'Sullivan et al. 2004).

The patterns of fractures among Graphisoft men are consistent with the types of higher-energy and direct injuries linked with manual labor, such as farming, animal handling, and construction. It is conceivable that male residents experienced indirect fractures related to accidental jumps/falls from walls, ladders, carts, or buildings. Impacts from various hand tools, animals, or larger farm equipment or carts may account for the direct force injuries. Although the injuries are best explained by higher-energy rural or industrial activities, given the difficulty in assessing probable injury cause, unfortunate urban accidents, or even interpersonal violence, cannot be entirely ruled out.

As it is often not possible to determine when an injury was sustained, and because skeletal trauma accumulates over a person's life, multiple fractures in a single individual may be caused by more than one injury event (Glencross 2011; Judd 2002a). Two Graphisoft males (2008.14.434, *adultus*; 2008.14.132, *maturus*) and one female (2008.14.184, *maturus*) had multiple fractures. Clinically, paired injuries to the medial malleolus and distal fibula, fractures present in the left ankle of individual 2008.14.434, often occur as the result of a single pronation-external rotation event of the ankle (Cooper 2000). It is not possible to determine if the fractures of the other two individuals occurred in one or two traumatic events. In some contexts, repeat trauma, or injury recidivism, may indicate intense and habitual exposure to dangerous activities, or indicate changing risks throughout the life course (Glencross 2011; Judd 2002a; Smith et al. 1992). For example, as a young adult, an individual may have experienced higher-energy injuries associated with physically dangerous activities, followed by fragility type fractures associated with bone loss in old adulthood. Even if injury recidivism is present, this does not change the fact that the extremity fractures at Graphisoft were predominantly lower energy injuries linked with mobility, and all the fracture types exhibited by individuals with multiple trauma are best associated with underfoot accidents.

In some respects, the male and female fracture frequencies and distributions were similar to those identified at Zadar, an urban site in the neighbouring province (*Dalmatia*). However, the significantly higher frequencies of female radial and ulnar trauma and greater odds of male humeral trauma at Zadar indicate differences in the dangers present in these two urban communities. Novak and Šlaus (2010) suggest that the high fracture frequencies at Zadar may be related to high population density and overcrowding, leading to a greater risk for both accidental and interpersonal trauma (e.g., Boyce 1998; Razavi et al. 2011). At the other comparative sites, differences in fracture distribution were most evident among the men, a fact that is possibly explained by the presence of specialist focuses in different communities. For example, of the comparative sites, Cirencester is the only site known to have focused on quarrying, a dangerous activity that may explain the significantly higher rates of trauma to the tibiae and fibulae (Burnham and Wacher 1990).

While the fracture frequencies indicate that some hazardous activities were present at and around Graphisoft, the comparative sites suggest that they were probably not as dangerous, or did not employ as much of the population, as in other areas of the Roman world. The prevalence and distribution of both male and female fractures at Graphisoft is most similar to the data from rural, Continental Croatia. The comparable frequency and distribution of fractures between the Pannonian border communities of Aquincum and the Continental Croatian sites suggests a similarity in the activities of border communities, regardless of settlement size.

4.1 Healing and Treatment

Classical authors knew the importance of rapid and effective fracture reduction, and also recognized complications associated with certain difficult to manage fracture types and locations (Brorson 2009). Roman physicians were trained by practical experience and apprenticeship, rather than in medical schools, and remedies from medicine makers and magicians may have been considered as alternatives to a doctor’s care (Cilliers and Retief 2006; Redfern 2010;

Scarborough 1970). Although medicine was not standardized in the Roman world, physicians were typically present in each settlement, and specialists were accessible in larger cities (Zsidi et al. 2004). *Aquincum* was no exception; a military hospital (*valetudinarium*) has been identified in the legionary fort, and a number of probable physicians have been identified in the *Aquincum* civil town cemeteries based on the inclusion of medical instrument sets, medications, and inscriptions in graves (Zsidi et al. 2004). The identification of doctors associated with the civil town suggests that the people here may have had access to some degree of medical treatment if they could afford it (Zsidi et al. 2004).

Based on the evidence for physicians in the *Aquincum* civil town, it is perhaps not surprising that 16 of the 23 fractures in the Graphisoft assemblage are well-healed and aligned. None possess skeletal evidence of inflammation. No asymmetry was macroscopically observed that might indicate nerve injury. Only one fracture, a perimortem spiral fracture to a right femur (2008.14.472), provides possible evidence for vascular damage (Figure 10). Arterial injury and blood loss are serious complications of diaphyseal femoral fractures, and may have influenced the successful treatment and ultimate survival of this individual (Hamblen et al. 2007; Starr et al. 1996). The perimortem nature of this fracture suggests that the person probably died soon after sustaining his injury.

Figure 10 Perimortem spiral fracture to a right, mid-shaft femur of an *adultus* male (2008.14.472), depicted from left to right in posterior, medial, and anterior views.

Many of the skeletal elements at Graphisoft were fragmentary and missing the proximal and distal bone ends, which presented difficulties in the calculation of accurate OA prevalence. However, approximately one third of all bones with OA of the joint/joints were associated with fractures. This observation conforms to clinical literature that lists OA as a common fracture complication (Anderson et al. 2011). Small sample sizes prohibited description of the distribution of OA by sex, but the fact that the observable joint surfaces of fractures with deformity (i.e., linear and/or rotation) greater than 15 degrees all exhibit OA, provides further evidence to support the post-traumatic development of this condition in bones that have healed with deformities (Van Der Schoot et al. 1996).

None of the Graphisoft fractures demonstrate mal-union to the extent that they can be confidently classed as “unsuccessfully” healed, according to Roberts (1998a). The well-reduced nature of fractures at Graphisoft is comparable with results reported by Novak and Šlaus (2010) at Continental Croatia, and by Redfern (2010) at Romano-British sites in Dorset, UK; in both studies fractures were predominantly well-healed, suggesting that fracture treatment skills were known in these regions. Although the Graphisoft fractures meet Roberts’ (1998a) standards, seven of the Graphisoft fractures had marked deformities of 15 degrees or greater; three of these, all belonging to males, possess both angular and rotational deformities greater than or equal to 15 degrees. These three fractures included a spiral fracture to a radius and transverse fractures to a radius and mid-shaft humerus, fracture types that are clinically notorious for their instability (Fabry and Casteleyn 2014; Rommens 2014). The fact that only spiral and transverse fractures exhibited both linear and rotational deformities (greater than or equal to 15 degrees) suggests that these mal-united fractures may be related to fracture type, rather than the skill of the person treating them, or the poor compliance of the individual to treatment recommendations. However, the presence of some greater degrees of deformity does mean that healing "success" at *Aquincum* was likely governed by difficulties associated with reducing and stabilizing certain fracture types. As men were the only individuals to exhibit less stable fractures, it is logical that they are also the ones that exhibit evidence of poorly healed fractures.

5. Conclusion

The evidence from Graphisoft supports the hypothesis that males and females experienced different risks for limb trauma associated with labor and leisure related activities at *Aquincum.* Graphisoft males and females demonstrated approximately equal rates of cumulative limb trauma, almost all of which were well healed, and likely caused by accidental injury, especially underfoot accidents (e.g., slips and trips). Nearly half of the male fractures were the result of higher energy and/or direct forces; these injury causes were more likely to produce less-stable fractures with greater amounts of mal-union. Males likely encountered the greatest hazards, displaying fracture types and distributions suggestive of manual labor. There is no conclusive evidence to suggest that females also participated in strenuous activities; the fractures observed among women indicate dangers associated primarily with movement and mobility, that is, underfoot accidents. Despite a probable gendered difference in the hazards encountered by each sex, there is no evidence for a sex bias in fracture healing/treatment; men demonstrated a greater number of mal-united fractures, but this likely had more to do with instability inherent to certain fracture types than treatment ineptitude. The fracture evidence from Graphisoft suggests the presence of traditional gender roles at *Aquincum*, indicative of a Roman urban environment where men and women performed different activities. All people appear to have been on an equal "footing" when it came to managing their injuries in this Roman border province.

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